



46TH TURBOMACHINERY & 33RD PUMP SYMPOSIA
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GEORGE R. BROWN CONVENTION CENTER

Plunger Pump Station Vibration-Induced Cracks in Piping

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Wood

Author bios

Kelly Eberle, Wood, BSc, PEng, Principal Consultant

Kelly is a Principal Consultant with Wood (formerly BETA Machinery Analysis) since 1988. Kelly graduated from the University of Saskatchewan with a Bachelor of Science in Mechanical Engineering in 1986. He has been a professional member of APEGA since 1991. He has accumulated a wide range of design and field experience, particularly in the area of pressure pulsation analysis and mechanical analysis of reciprocating compressor and pump installations. The scope of his experience includes pulsation simulations, thermal flexibility studies, dynamic finite element analysis, structural analysis and foundation analysis.

Mena Ghattas, Wood, BSc, PE, Team Lead

Mena Ghattas works with Wood's vibration integrity group, which specializes in design, inspection, and consulting services related to static and transient piping vibration for onshore and offshore facilities. This includes requirements defined by the Energy Institute Guideline (Avoidance of Vibration Induced Fatigue Failure), as well as advanced analysis services such as dynamic pulsation analysis, dynamic structural analysis and rotating equipment analysis.



Objective

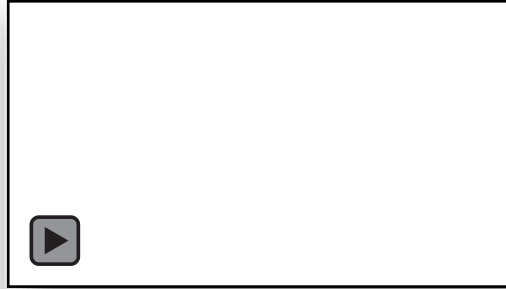
Demonstrate the risks and costs of excluding a pulsation analysis from a pump installation, as well as ways to mitigate the pulsation and cavitation risks.

Analysis approach

Field-measured pulsations and numerical simulations (1-D pulsation model).



Case study

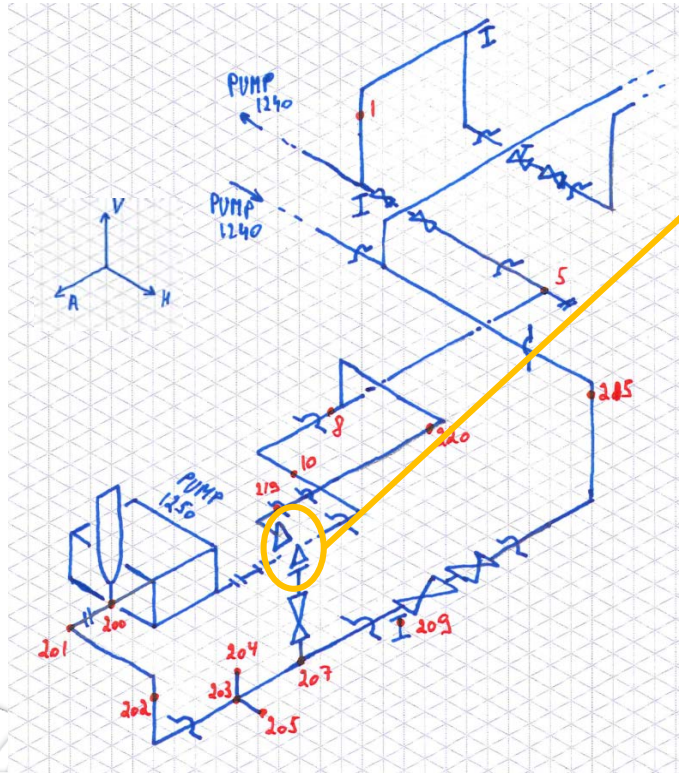


- (2) Quintuplex pumps
- 297 HP
- Liquid propane 416 GPM @ 400 RPM
- Speed range 200-400 RPM

6 months in operation, very high vibrations

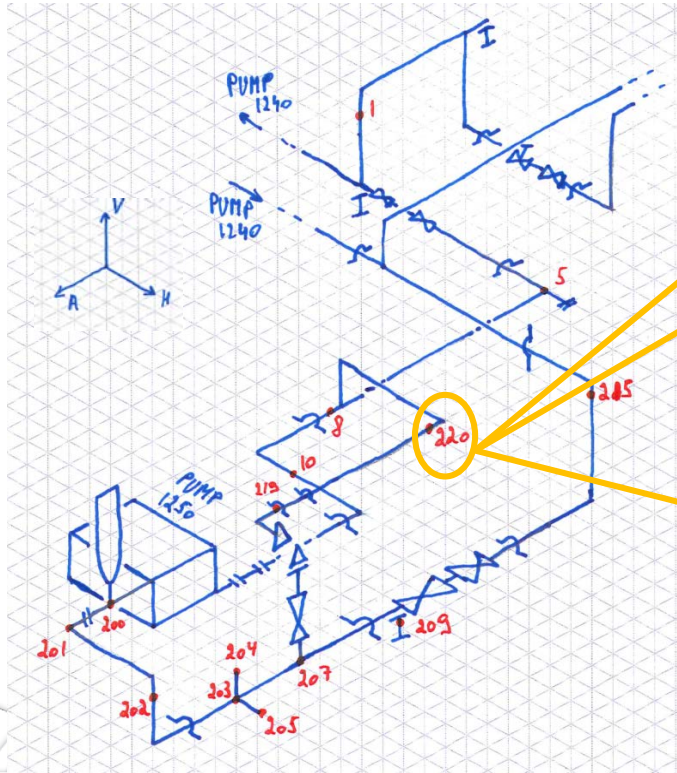


Site vibration measurements



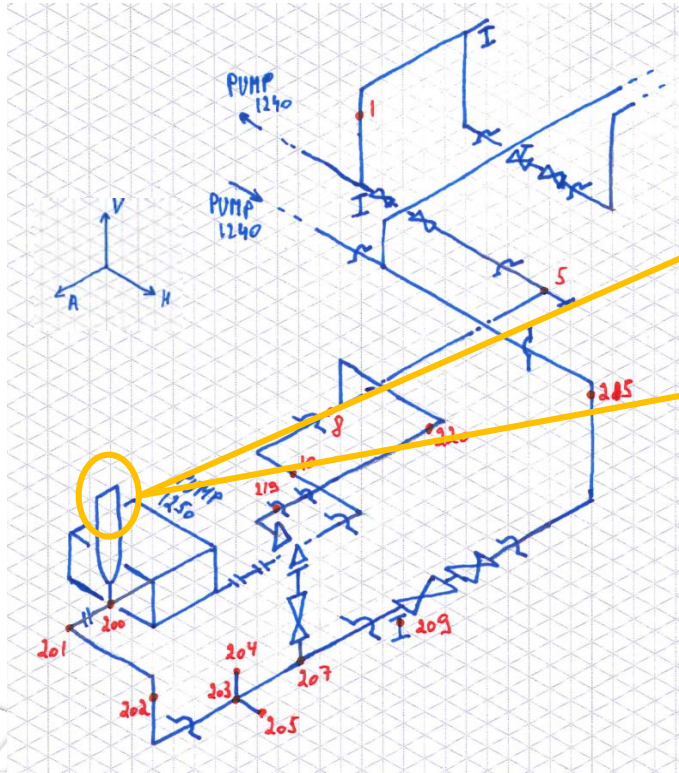
Location	Dir'n	Percent Guideline
PSV top	A	1192
PSV top	H	883
220	V	693
Dampener top	A	628
220	H	579
1	H	539
small bore near 5	A	399
Dampener top	H	392
5	A	392
204	-H	322
203	H	314
220	A	287
8	H	272
207	H	270
215	A	264
209	H	223
202	A	217
10	A	215

Site vibration measurements



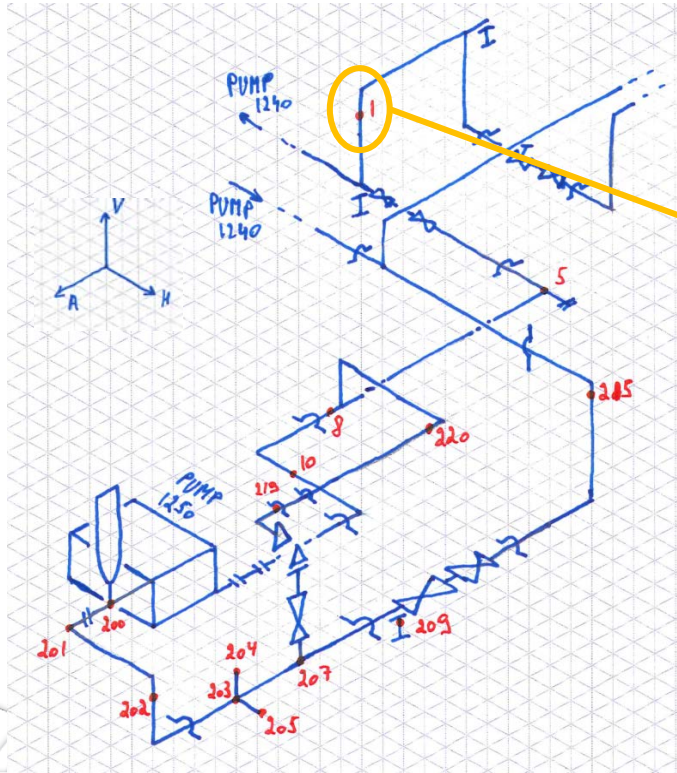
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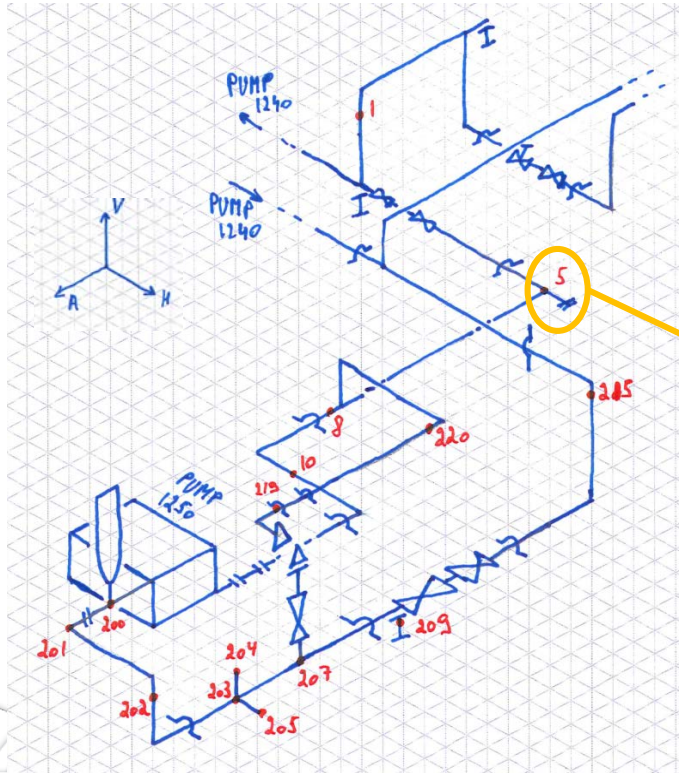
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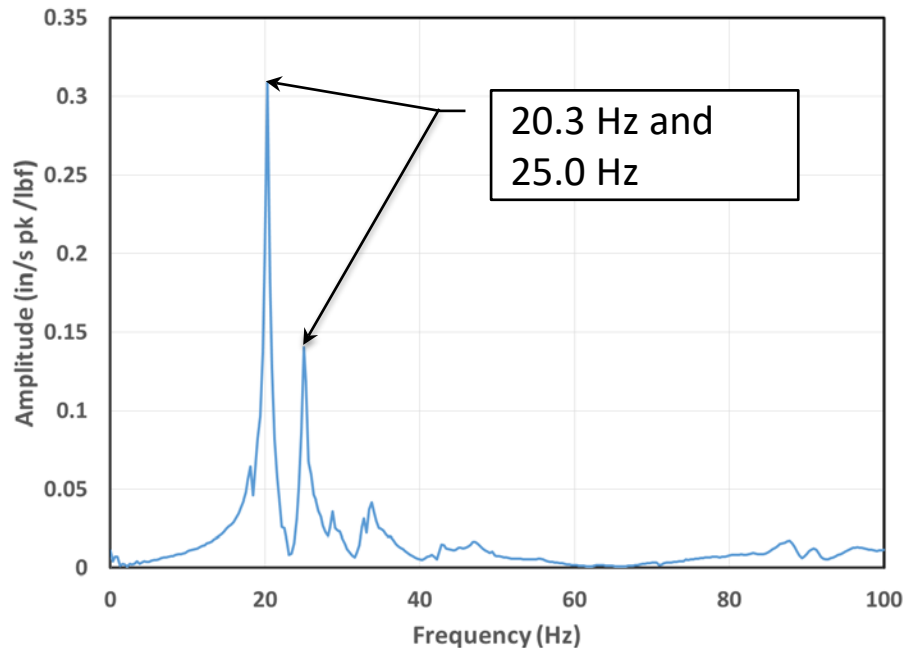


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Dampener site measurements

Mechanical natural frequency measurement



Vibration measurement

Location	Dir'n	Percent Guideline	Amplitude	Units	Freq. (Hz)
PSV top	A	1192	9.01	ips Pk	24.1
PSV top	H	883	6.85	ips Pk	24.7

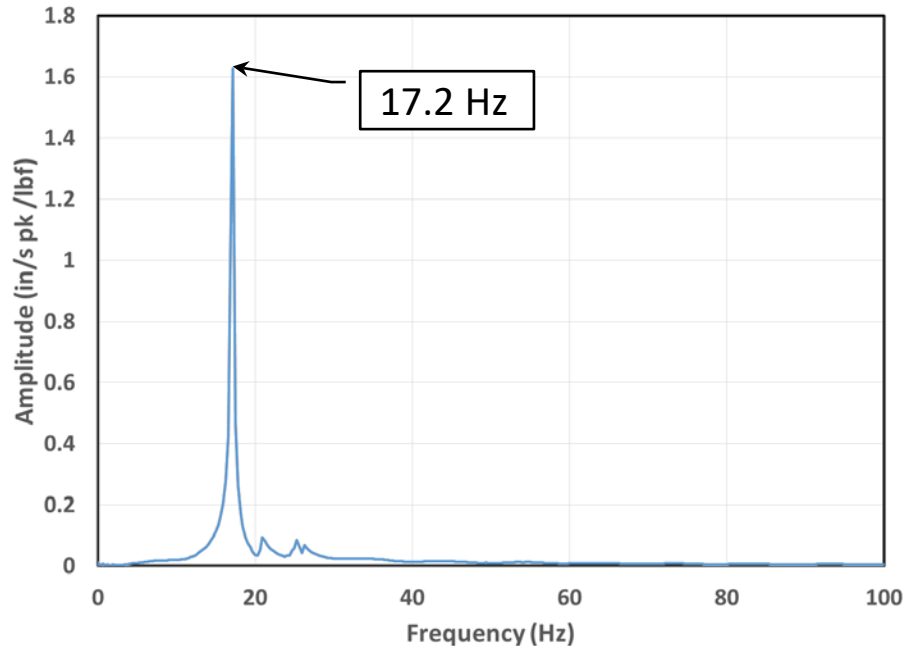
Maximum vibration is close the measured mechanical natural frequency (MNF).

Conclusion:

PSV is mechanically resonant

PSV site measurements

Mechanical natural frequency measurement



Vibration measurement

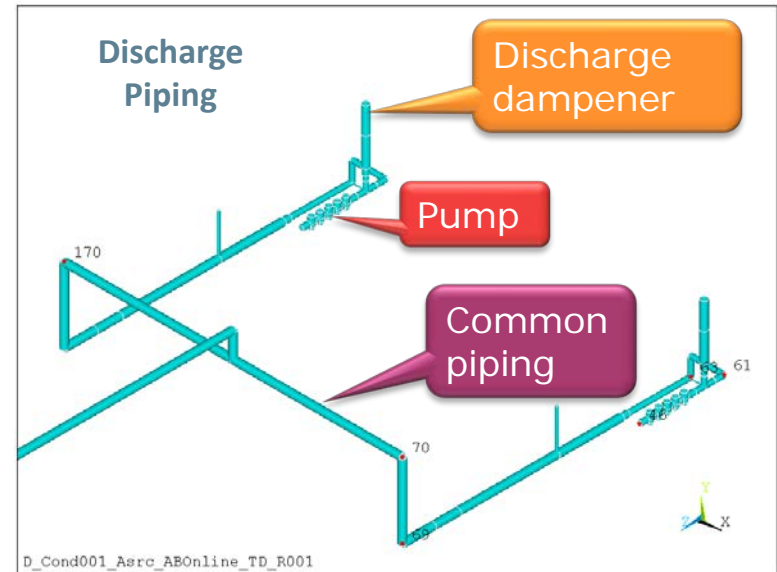
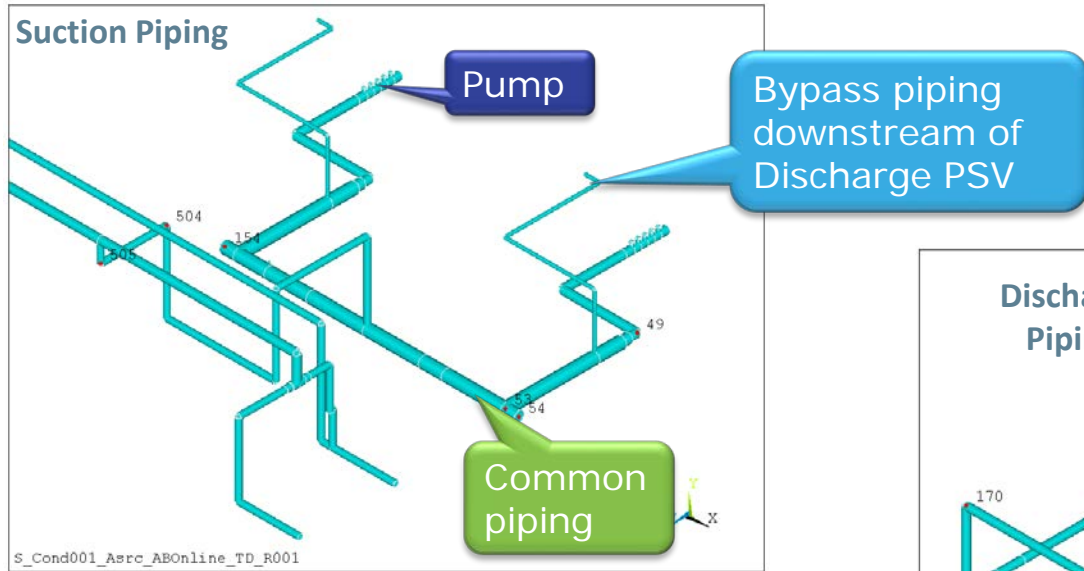
Location	Dir'n	Percent Guideline	Amplitude	Units	Freq. (Hz)
Dampener top	A	628	3.33	ips Pk	16.9
Dampener top	H	392	1.85	ips Pk	15

Maximum vibration is close the measured MNF.

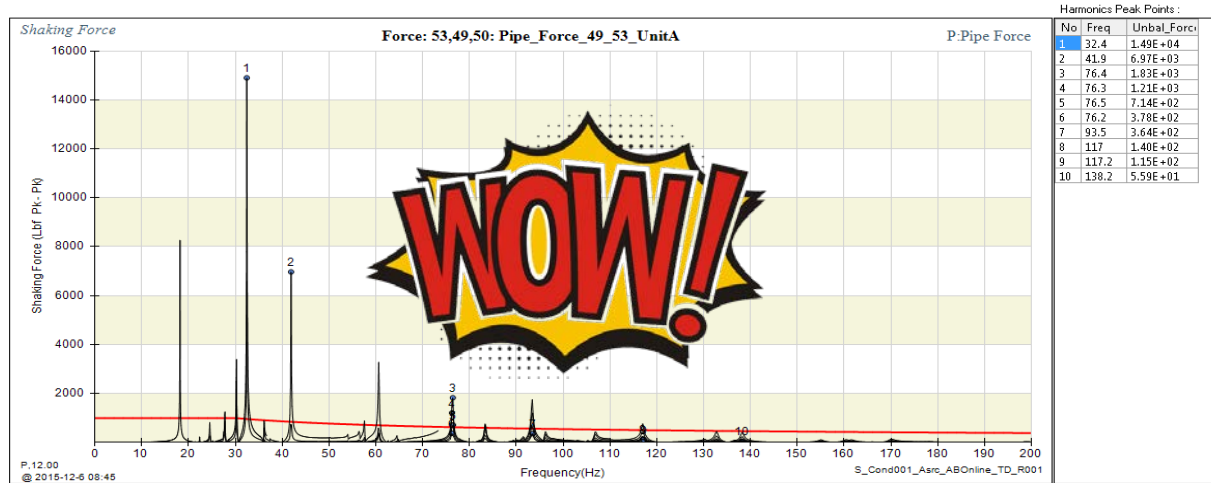
Conclusion:

Dampener is mechanically resonant

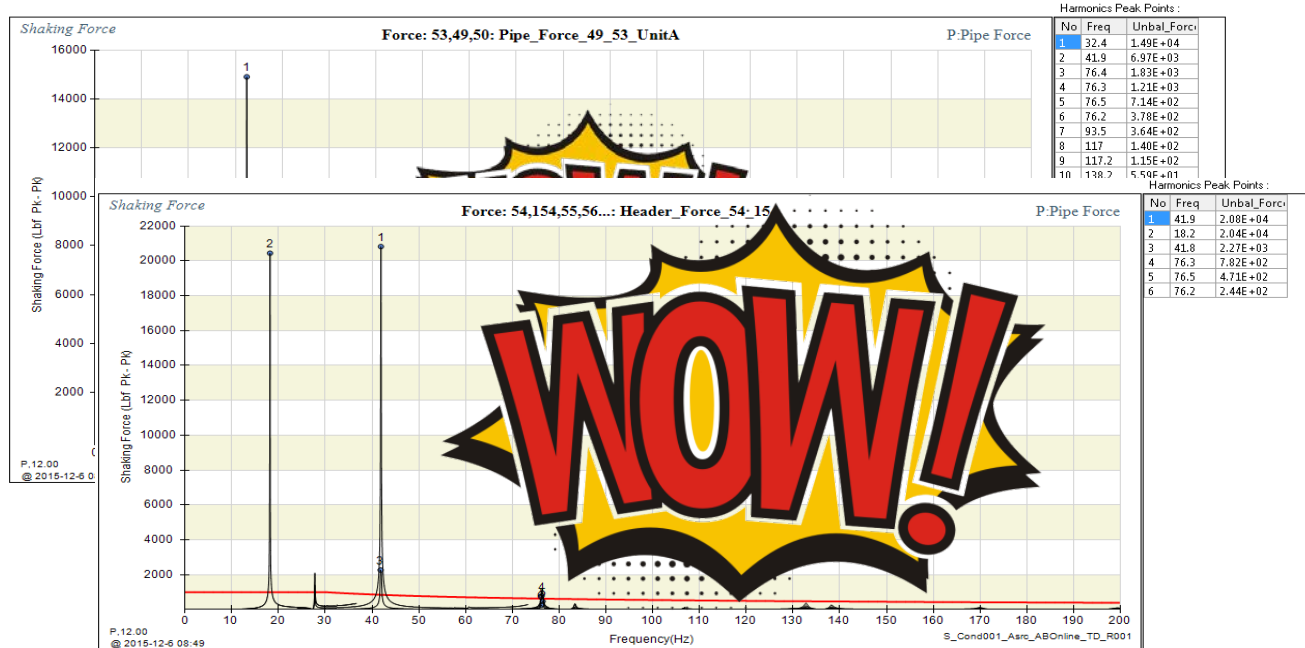
Pulsation model



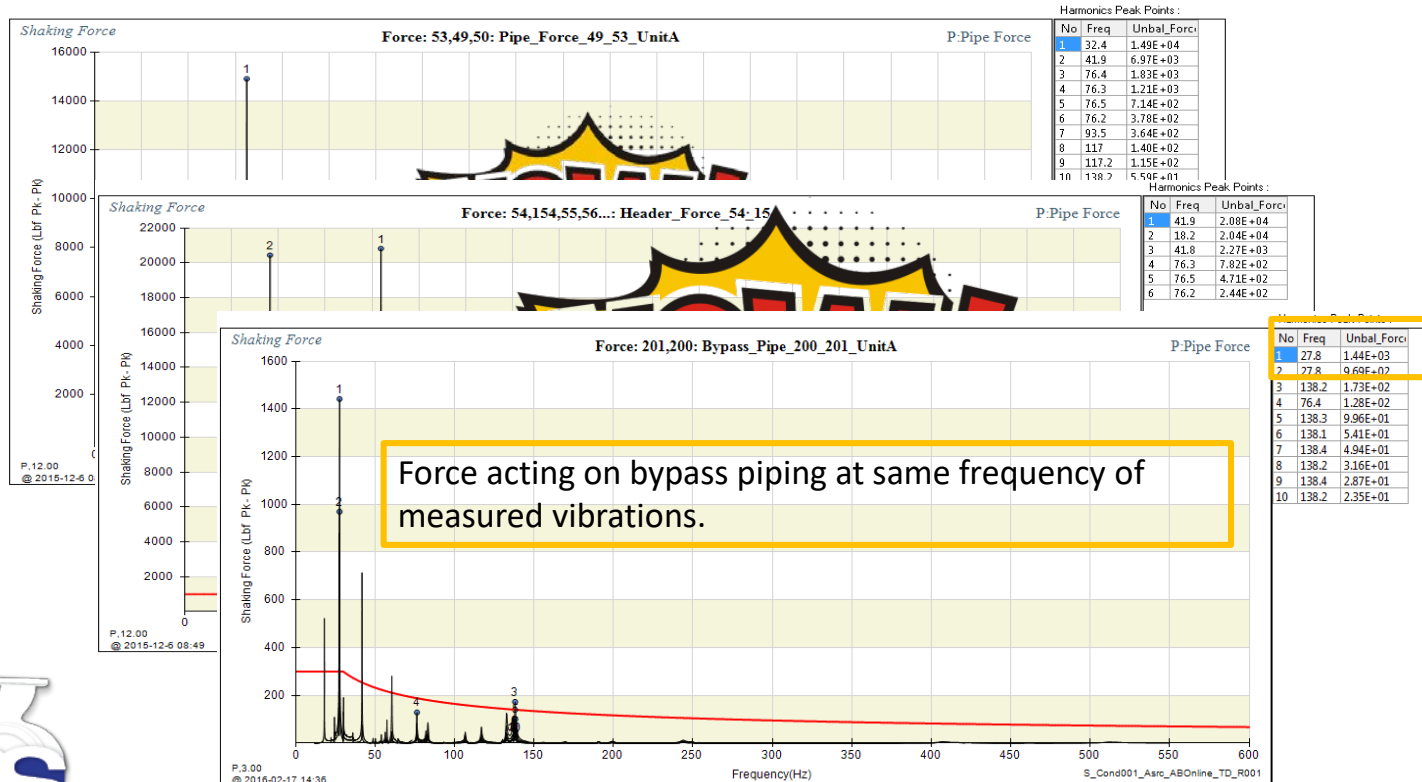
Pulsation model – shaking forces



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Pulsation model – shaking forces

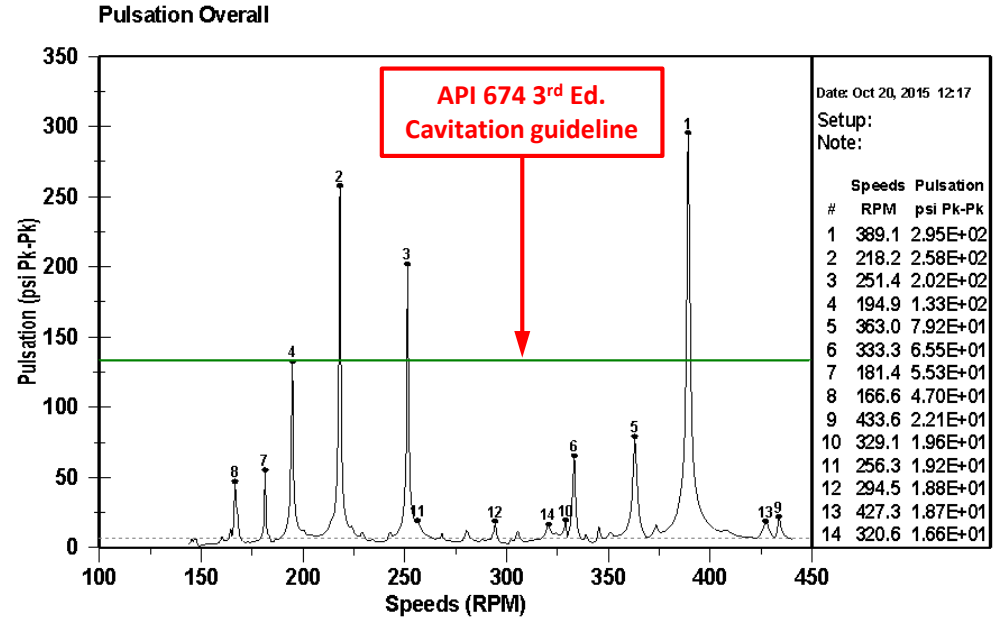
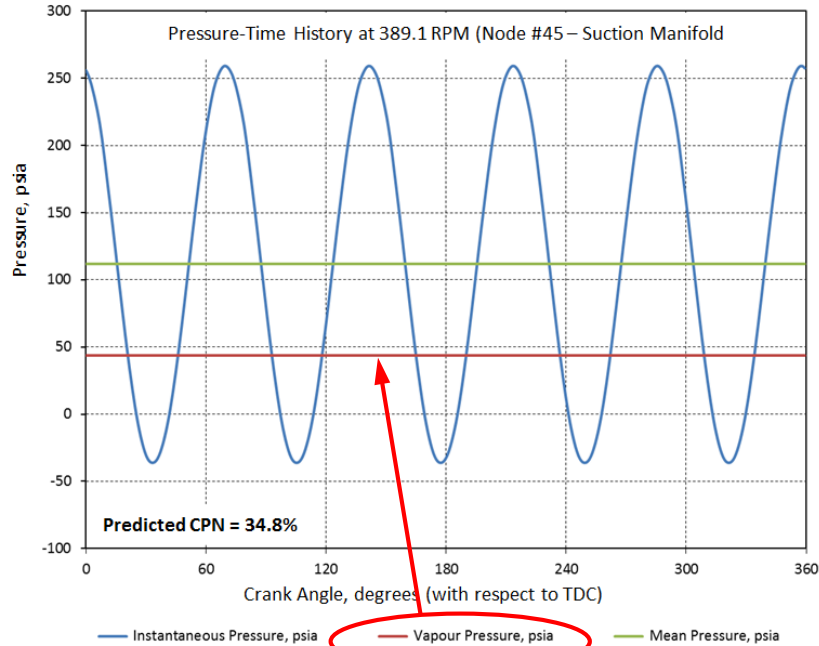
Pipe span	Existing (full speed 200 – 400 rpm) Lbf peak-peak	Existing (650 bbl/hr 200 – 218.5 rpm) Lbf peak-peak
45 – 48	5,100	1,020
48 - 49	7,220	1,580
49 - 53	14,900	4,920
200 - 201	1,440	309
201 - 202	6,980	139
54 - 154	20,800	12,100
57 - 500	2,410	524
500 - 501	3,180	695
501 - 502	2,150	473

Pipe span	Existing (full speed 200 – 400 rpm) Lbf peak-peak	Existing (650 bbl/hr 200 – 218.5 rpm) Lbf peak-peak
502 - 503	2,070	299
503 - 504	1,370	296
504 – 505	2,020	439
400 - 507	4,390	958
404 - 409	8,100	196
508 - 509	6,990	1,520
510 - 702	2,500	434
511 - 600	1,660	398
702 - 703	1,800	390

Shaking forces in other areas in the system.



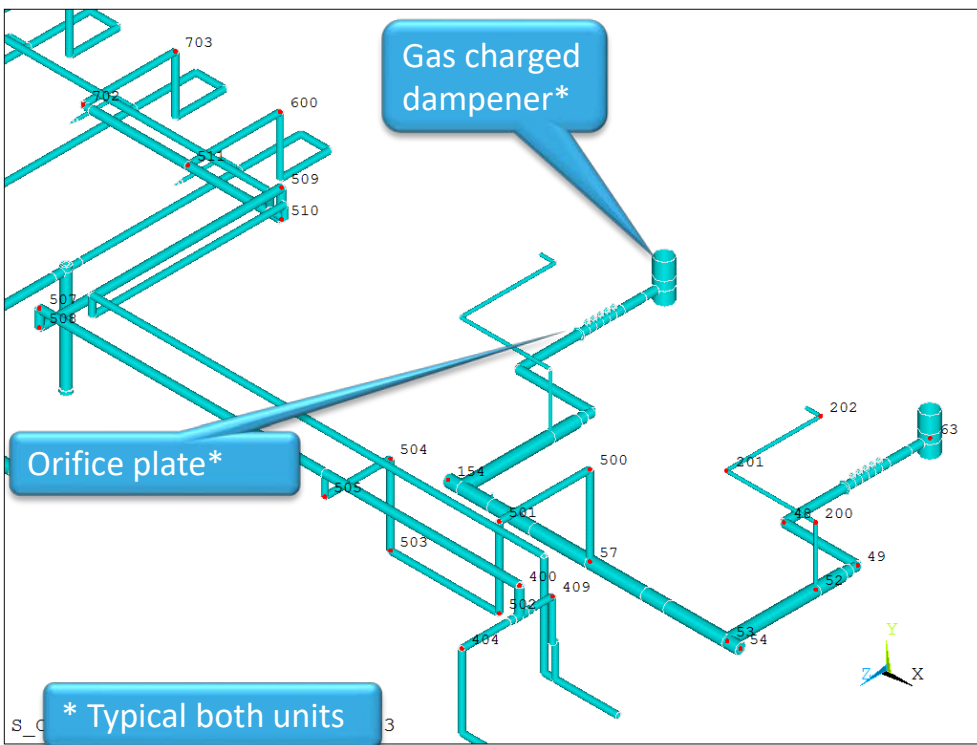
Pulsation model



Pulsations will lead to **CAVITATION** when operating at resonance



Short-term solution



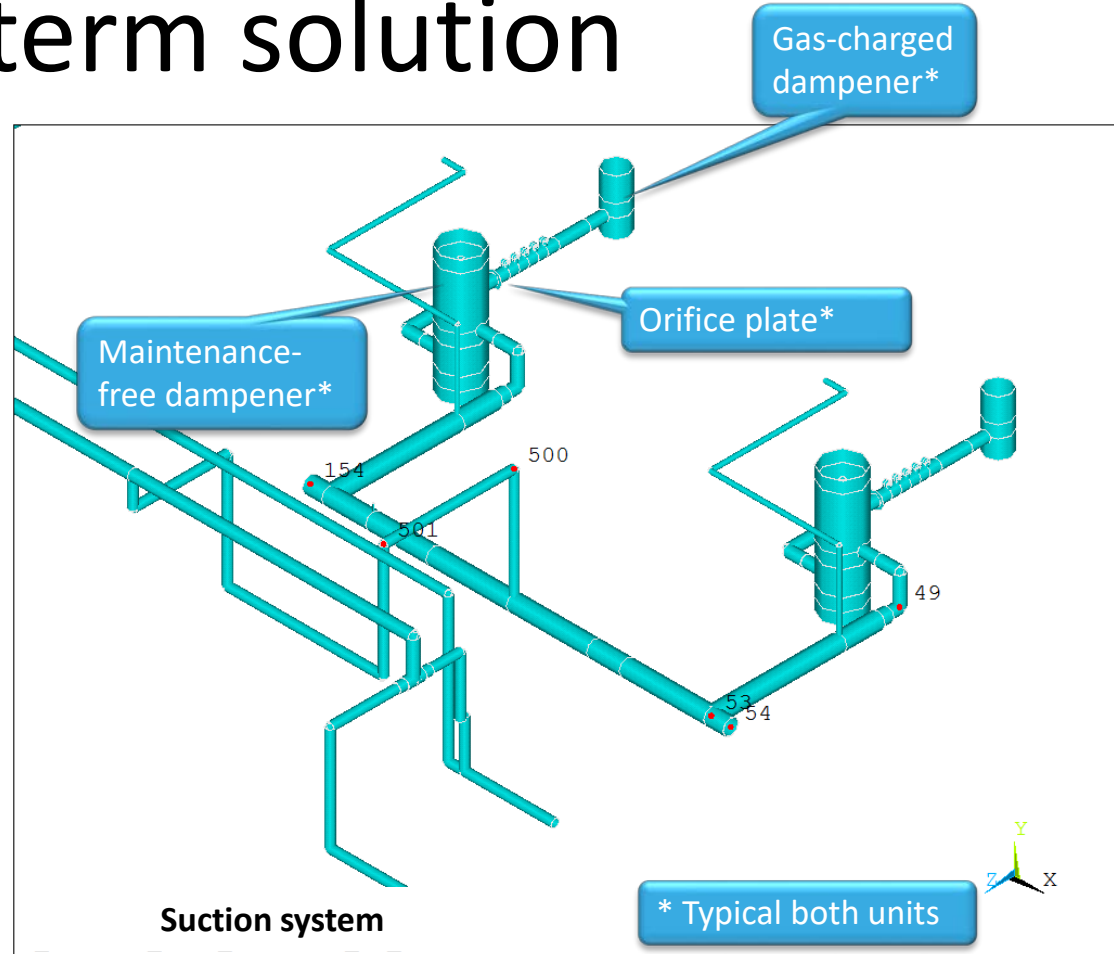
Shaking forces (lbf peak-peak)

Pipe span	Existing (full speed 200 – 400 rpm)	Existing (650 bbl/hr 200 – 218.5 rpm)	Short-Term (full speed 200 – 400 rpm)	Short-Term (650 bbl/hr 200 – 218.5 rpm)
45 – 48	5,100	1,020	1,820	253
48 - 49	7,220	1,580	1,880	163
49 - 53	14,900	4,920	2,970	410
52 - 200	1,140	275	214	35.1
200 - 201	1,440	309	187	47.5
201 - 202	6,980	139	309	53.8
54 - 154	20,800	12,100	2,890	462
57 - 500	2,410	524	474	43.3
500 - 501	3,180	695	807	55.9
501 - 502	2,150	473	323	45.1



Long-term solution

Allows for continuous operation over the complete speed range of 200-400 rpm



Site inspection - NDT

- Predicted forces in pulsation study are well above acceptable limits. Operator decided to evaluate piping integrity.
- NDT completed on piping and found 20 cracks



UNITS SHUT DOWN

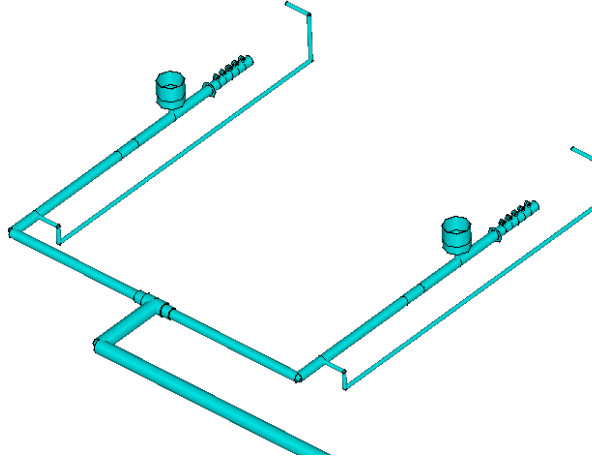
Replace and reroute piping

- Operator had to replace most piping due to cracks
- Improve piping layout and supporting
 - Reduce number of elbows
 - Avoid elevated piping (support stiffness related to height³)
 - Avoid unsupported elbows
 - Avoid redundant small-bore connections

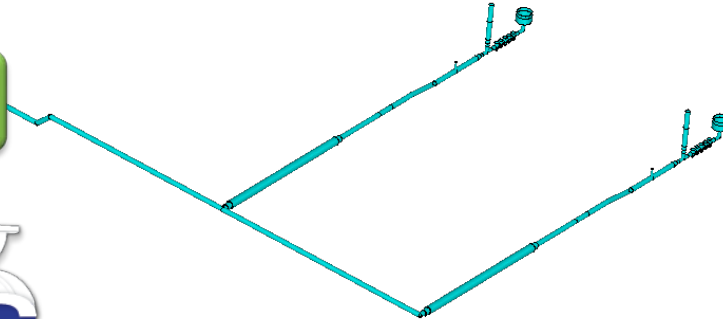


Replace and reroute piping

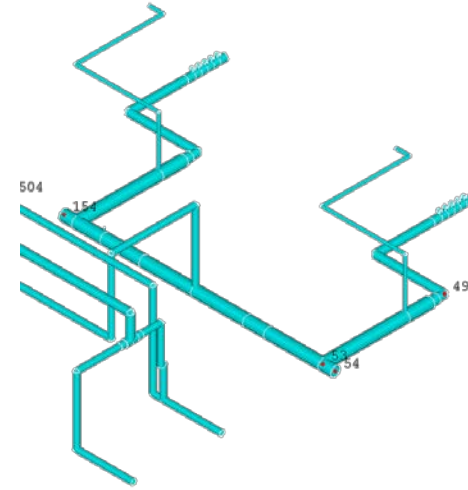
New suction layout



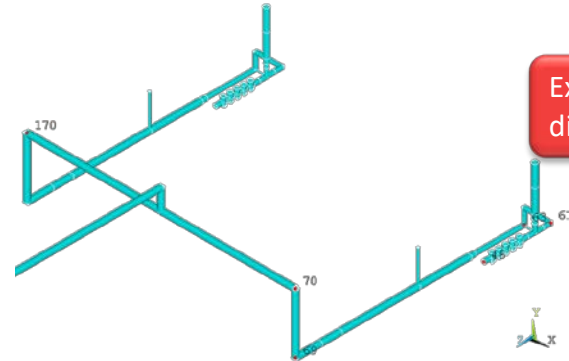
New discharge layout



Existing suction layout



Existing discharge layout



Recommendations with new layout

Suction

- 3.125" ID orifice plates (pump manifold inlets & vessel outlet)
- 20-gallon gas-charged dampeners
- Vessel 30" OD x 72" S/S acoustic filter

Discharge

- Secondary 5-gallon gas-charged dampeners
- 10" XS line expansion

Suction system forces (lbf peak-peak)				
Design #	20 gal dampener	20 gal dampener + Orifice plates	20 gal dampener + orifice plates + vessel	
Lateral piping	15,000	2,600	1,200	
Bypass piping	450	500	100	
Pump header	19,000	3,500	500	
Main header	1,800	1,800	400	
Header pipe span	1,760	950	184	
Pressure drop element	Orifice plate (manifold inlet)	Orifice plate (Vessel outlet)	Internal choke tube	External choke tube
Pressure drop (psi) @ 400 RPM	2.46	2.44	0.16	0.05



Design implementation

- Add suction gas charged dampener
- Add orifice plate at suction pump manifold
- Add discharge secondary gas charged dampener



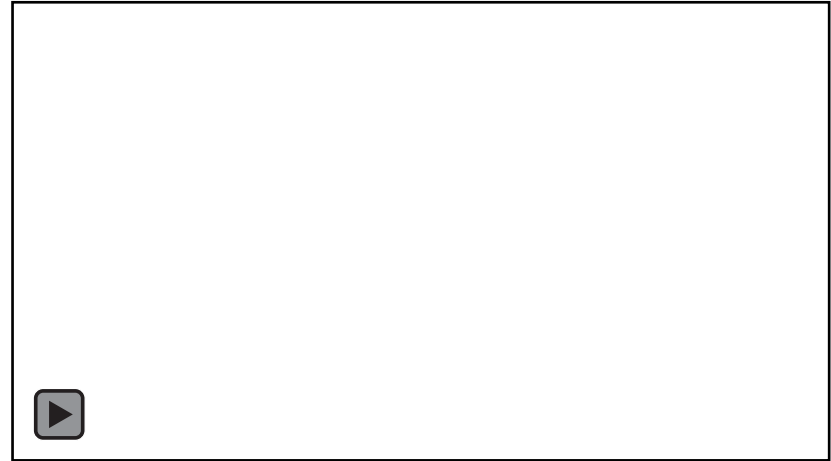
Design implementation

- Add suction gas charged dampener
- Add orifice plate at suction pump manifold
- Add discharge secondary gas charged dampener
- Add proper support



Conclusions

- Pulsation study **MUST** be completed on pumps > 50 HP
- Orifice plates can be crucial to reducing pulsations and avoiding cavitation
- Interaction between multiple units should be considered
- Pipe routing and support is vital to mitigating vibrations



Questions

